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Optimizing Overall Equipment Effectiveness in real-time with OPC UA: improving performance in smart manufacturing systems.

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Abstract:	In today's competitive industrial landscape, maximizing asset efficiency is crucial for achieving global success. By optimizing resource allocation and minimizing waste, organizations can significantly enhance their operational efficiency, boost productivity, and strengthen market competitiveness. To effectively assess and improve these operations, industries need to adopt Key Performance Indicators (KPIs) which addresses the requirement to monitor and indicate process efficiencies. Among the various manufacturing KPIs, Overall Equipment Effectiveness (OEE) is a critical metric for evaluating machine performance. This study focuses on the implementation of OEE using OPC UA (Open Platform Communications Unified Architecture) which is the industrial communication standard in smart manufacturing environments. This study emphasizes the process of integrating data from CNC machines and plant schedules, the study shows how real-time OEE is computed and identifies sources of operational losses. The developed solution, which can be deployed either on-premises or in the cloud, automates the OEE calculation process. It provides insights that drive productivity gains and operational flow which are the key areas for improvement. Key objectives of this implementation include the development of real-time OEE formulations and accurate data aggregation for in-depth analysis. Deployed within the Smart Manufacturing Demo and Development Cell (SMDDC) at the Central Manufacturing Technology Institute (CMTI), this solution aims to enhance operational efficiency and drive significant productivity improvements. By leveraging real-time data and advanced analytics, this approach promises to deliver substantial benefits in terms of both productivity and competitive advantage.
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Highlights

1. Among the various manufacturing KPIs, Overall Equipment Effectiveness (OEE) is a critical metric for evaluating machine performance.
2. This study focuses on the implementation of OEE using OPC UA (Open Platform Communications Unified Architecture) which is the industrial communication standard in smart manufacturing environments.
3. The study shows how real-time OEE is computed and identifies sources of operational losses.
4. By leveraging real-time data and advanced analytics, this approach promises to deliver substantial benefits in terms of both productivity and competitive advantage.

Optimizing Overall Equipment Effectiveness in real-time with OPC UA: improving performance in smart manufacturing systems.

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Abstract

In today's competitive industrial landscape, maximizing asset efficiency is crucial for achieving global success. By optimizing resource allocation and minimizing waste, organizations can significantly enhance their operational efficiency, boost productivity, and strengthen market competitiveness. To effectively assess and improve these operations, industries need to adopt Key Performance Indicators (KPIs) which addresses the requirement to monitor and indicate process efficiencies. Among the various manufacturing KPIs, Overall Equipment Effectiveness (OEE) is a critical metric for evaluating machine performance. This study focuses on the implementation of OEE using OPC UA (Open Platform Communications Unified Architecture) which is the industrial communication standard in smart manufacturing environments. This study emphasizes the process of integrating data from CNC machines and plant schedules, the study shows how real-time OEE is computed and identifies sources of operational losses. The developed solution, which can be deployed either on-premises or in the cloud, automates the OEE calculation process. It provides insights that drive productivity gains and operational flow which are the key areas for improvement. Key objectives of this implementation include the development of real-time OEE formulations and accurate data aggregation for in-depth analysis. Deployed within the Smart Manufacturing Demo and Development Cell (SMDDC) at the Central Manufacturing Technology Institute (CMTI), this solution aims to enhance operational efficiency and drive significant productivity improvements. By leveraging real-time data and advanced analytics, this approach promises to deliver substantial benefits in terms of both productivity and competitive advantage.

Keywords: Overall Equipment Effectiveness, Machine-to-Machine Communication, OPC UA Technology, Real-time OEE Computation, Data Aggregation Techniques, Smart Manufacturing.

Introduction

Today, the global manufacturing sector is swiftly evolving to maintain competitiveness and optimize resource use in production environments. At present, manufacturing industries are moving at a rapid pace to optimize and sustain themselves in the highly competitive market and to use the resources optimally for production. Smart manufacturing integrates artificial intelligence, big data analytics, and the Industrial Internet of Things (IoT) to enable real-time data collection and analysis, facilitating predictive maintenance and proactive decision-making to optimize efficiency [1]. This integration not only enhances operational efficiency but also promotes sustainability through resource optimization, waste reduction, and energy efficiency, ensuring alignment with environmental stewardship goals [2]. Consequently, continuous improvement in production efficiency on the shop floor becomes crucial for minimizing losses and optimizing equipment performance. Central to these advancements are OPC UA (Open Platform Communications Unified Architecture) and machine-to-machine (M2M) communication, which enhance connectivity and interoperability in smart manufacturing environments. OPC UA provides a standardized communication framework for secure and reliable data exchange between industrial automation systems, supporting scalable integration across heterogeneous devices and platforms [3]. Complementing this, M2M communication enables direct interaction between machines, sensors, and devices without human intervention, further enhancing automation and efficiency [4]. Together, these technologies foster transparency, flexibility, and responsiveness, laying a strong foundation for Industry 4.0 initiatives [5]. A key metric for evaluating the performance of these technologies is Overall Equipment Effectiveness (OEE). Analyzing OEE reveals significant losses due to setup and adjustment, idle time, and process faults, highlighting the need for proactive maintenance scheduling, failure resolution, and process optimization [6]. Effective prioritization of maintenance tasks optimizes production systems, focusing on metrics such as mean time between stops (MTBS), mean time to resume from stops (MTTR), and buffer size [7]. Moreover, integrated digital solutions enhance sustainability and efficiency in manufacturing by addressing these issues comprehensively [8]. Preventive and predictive maintenance, along with condition-based monitoring, play crucial roles in influencing OEE and overall equipment reliability across various sectors [9]. For instance, OEE metrics are applied in industries like automation and aircraft manufacturing to address specific challenges and enhance production efficiency [10]. In other sectors, these metrics are utilized to reduce losses and boost productivity [11]. These concerted efforts not only optimize production but also mitigate losses and maintain competitiveness, contributing to a more agile and adaptive manufacturing ecosystem [12][13]. Moreover, the adoption of advanced manufacturing techniques such as additive manufacturing and robotics further enhances production capabilities and efficiency [14]. These technologies streamline operations, reduce manual labor dependencies, and improve product quality, aligning with the goals of smart manufacturing. With a comprehensive understanding of the principles and benefits of OEE in smart manufacturing contexts, the next step was the practical implementation within our operational environment. For instance, OEE metrics are applied in industries like automation and aircraft manufacturing to address specific challenges and enhance production efficiency [15]. In other sectors, these metrics are utilized to reduce losses and boost productivity [16]. These concerted efforts not only optimize production but also mitigate losses and maintain competitiveness, contributing to a more agile and adaptive manufacturing ecosystem [17]. Moreover, the adoption of advanced manufacturing techniques such as additive manufacturing and robotics further enhances production capabilities and efficiency [18]. These technologies streamline operations, reduce manual labor dependencies, and improve product quality, aligning with the goals of smart manufacturing [19]. With a comprehensive understanding of the principles and benefits of OEE in smart manufacturing contexts, the next step was the practical implementation within our operational environment. Leveraging insights from diverse research studies [20-30], CMTI as a research institute has successfully implemented OEE frameworks to enhance operational efficiency and promote sustainable manufacturing practices. Recent research has further advanced the understanding and application of OEE in smart manufacturing. For instance, the digital shadow concept using OPC UA for CNC machines enables real-time monitoring and optimization [31]. Industry 4.0 technologies, including MES and ERP integration, are crucial for implementing smart factories and addressing legacy system complexities [32]. Evaluations of CNC machines using OEE methods highlight the importance of downtime management and speed optimization [33]. Additionally, service-oriented approaches for OEE calculation using OPC UA improve accuracy and timeliness [34]. These advancements underscore the continuous need for innovation and integration to enhance production efficiency and competitiveness. With a comprehensive understanding of the principles and benefits of OEE in smart manufacturing contexts, the next step was practical implementation within our operational environment. Leveraging insights from diverse research studies [31-34], CMTI as a research institute has successfully implemented OEE frameworks to enhance operational efficiency and promote sustainable manufacturing practices. OPC UA which is most widely used for integration, play a crucial role in enhancing ma-chine connectivity, particularly through real-time data exchange and monitoring. Martinov et al. (2023) illustrate this with CNC machine digital shadows in private clouds, using OPC UA for precise process simulation and validation, improving system integration and equipment utilization. Wu et al. (2024) highlight Industry 4.0's impact on smart factories, integrating MES, ERP, and cloud systems to enhance data flow, monitoring, and analytics. The implementation of the Overall Equipment Effectiveness (OEE) framework within smart manufacturing environments at CMTI resulted in a 12% increase in production efficiency and a 10% reduction in operational downtime. These improvements were achieved through enhanced monitoring and maintenance, leading to cost savings and increased production accountability on the shop floor.

Methodology

Data Visualization and Shopfloor Overview

Visualization of data is where raw operational data is transmitted from OPC UA server, acting as the central hub for aggregating and managing data. As illustrated in **Figure. 1** the data acquisition begins at the CNC Machine and its CNC controller, and from the OPC UA Server, processed data is directed to the OEE Dashboard through HTTP/REST protocol, providing real-time insights into Overall Equipment Efficiency (OEE) metrics. Simultaneously, an OPC UA Client maintains secure communication with the OPC UA Server, ensuring smooth data exchange. Once collected, the analyzed data is stored in a database for future reference and analysis. To enable external access and integration with other systems, a router facilitates communication via TCP/IP protocols, extending connectivity to external systems and the internet.

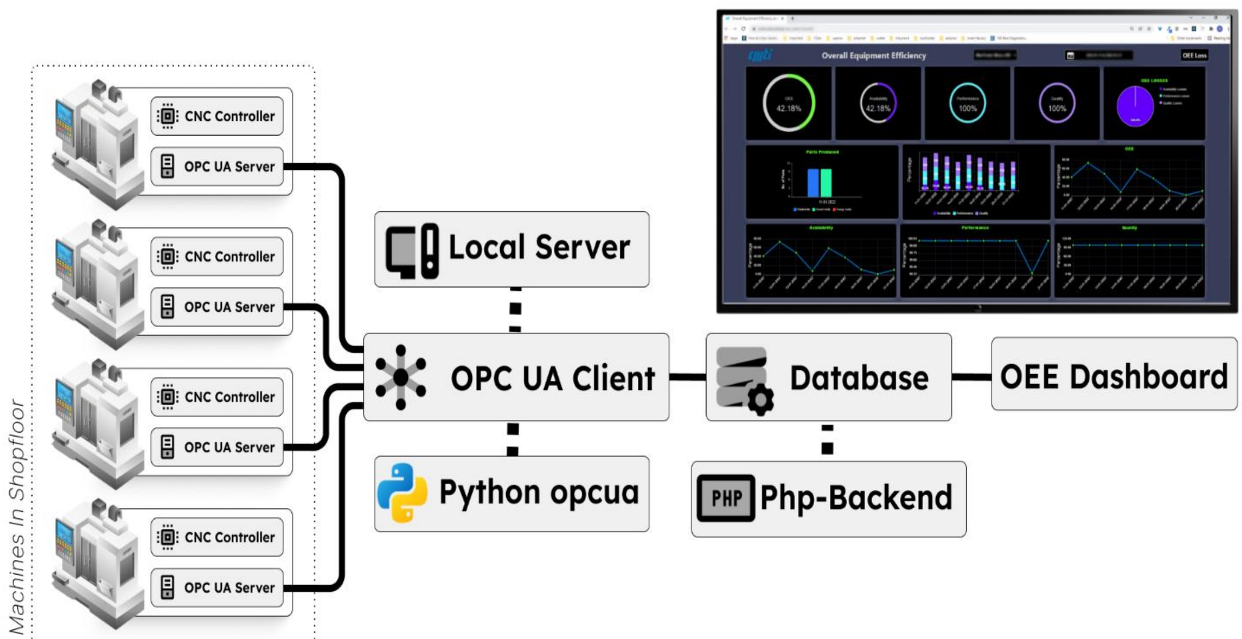

Figure 1: Basic architecture of data collection and monitoring for overall equipment efficiency (OEE) of machines on a shop floor setup.

Figure. 2 shows a manufacturing setup for calculating OEE to using OPC UA parameters is visualized. It shows three CNC machines with an OPC UA server, which monitors key machine parameters such as speed override, feed rate override, spindle speed, operation mode, and machine status. These parameters are critical for evaluating the three components of OEE: Availability, Performance, and Quality. The architecture includes an OPC client configuration that allows real-time OEE evaluation and visualization, helping in monitoring and optimizing production processes.

Figure 2: Visual representation of process flow of machine parameters from OPC UA Server to evaluating OEE components such as availability, performance and quality.

OEE parameters are mainly required for performing calculations along with its associated factors: **machine status:** Indicates the status of the machine (e.g., idle, production, off). The status of the machine is determined by using both opMode and cycleStart events from OPC UA, **machine OFF time:** Total time the machine is in OFF state which is shown in the form of horizontal stack chart in **Figure. 3**. This is determined when the OPC UA Server is unreachable, thereby denoting the machine is OFF until changes to idle.

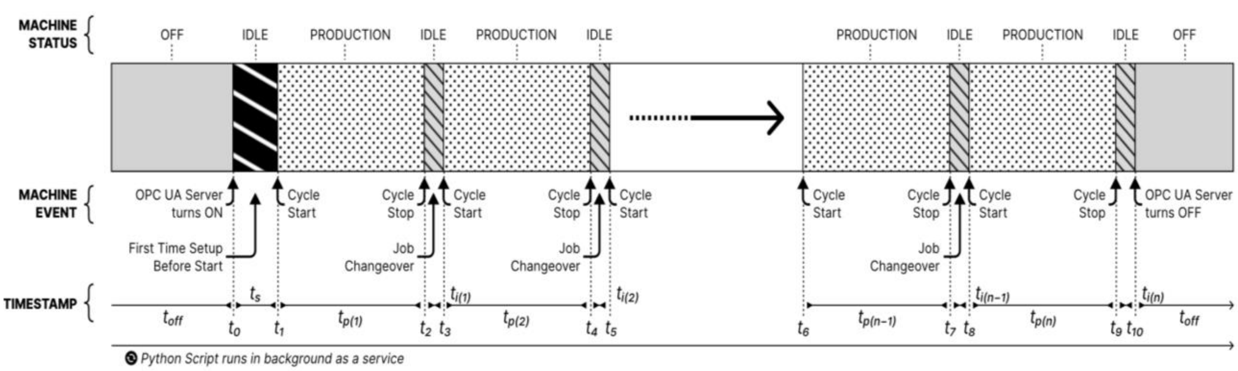

Figure 3: OEE Machine Status & Events Horizontal Stack Chart.

The machine OFF-time, Idle-time, Production-time is considered as the summation of each individual time cycle of occurrences. By considering the cumulative time for each operational state (OFF-time, Idle-time, Production-time), the system can accurately reflect the machine's performance over time.

$$Machine\ \boldsymbol{OFF}\ Time = \sum t_{off}$$

machine IDLE time: Total time the machine is in IDLE state. This is determined by the condition that the cycleStart event has not occurred regardless of the opMode (i.e., 0-JOG MODE, 1-MDI, 2-AUTO)

$$Machine\ \boldsymbol{IDLE}\ Time = \sum_{j=1}^{n} ti_j$$

machine PRODUCTION time: Total time the machine is in PRODUCTION state. This is determined by the event interval of cycleStart turning True with opMode in 3-AUTO state and cycleStart turning False again,

$$Machine\ \boldsymbol{PRODUCTION}\ Time = \sum_{i=1}^{n} tp_i$$

In **Figure. 4** a detailed overview of OEE computation is covered by breaking down the total shift duration into various components, highlighting the different types of losses that affect production. It begins with the total shift duration, from which planned non-production times, such as breaks and meetings, are subtracted to determine the planned production time (T_{pp}). Within this planned production time, actual production time (T_{ap}) is calculated by excluding unplanned downtimes like equipment breakdowns. The diagram also illustrates performance by comparing the ideal production quantity (N_{ip}) to the actual produced quantity. The duration of the planned shift in minutes is considered according to the working shift hours as shown in **Figure. 4**.

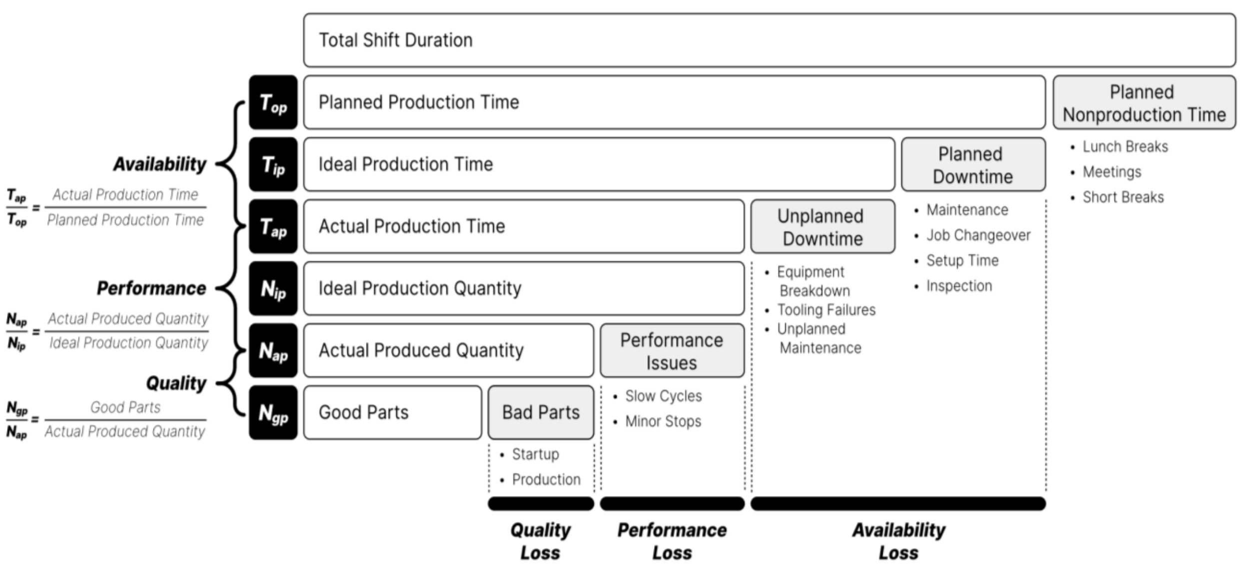

Figure 4: OEE Parameters & Losses Waterfall Diagram

The development of the Overall Equipment Efficiency (OEE) module using Machine to Machine (M2M) Connectivity Protocol and Open Platform Unified Architecture (OPC UA) for Smart Manufacturing involves several key steps. First, the requirement analysis identifies industry-specific needs such as production quality improvement and global market competitiveness and defines objectives for enhancing asset efficiency using OEE as a Key Performance Indicator (KPI). Next, OPC UA functionality is implemented on CNC machines, including the configuration of server IPs, security options, and the identification of relevant variables for data transmission.

An OPC UA client is then installed to facilitate communication between the CNC machine and the server. Finally, the connection between the CNC machine and the server is established using OPC UA protocols.

The key parameters taken from the CNC controller's OPC UA Server, which are read and stored in the database using the OPC UA Client, are detailed below. These parameters are essential for computing the OEE and OEE losses module. Table 1 shows the OPC UA parameters used for computation and analysis of OEE from OPC UA. Various parameters tracked within a manufacturing environment are depicted, along with their corresponding data types and OPC UA Node Ids for communication.

Table 1: OPC UA Parameters used for computation and Analysis of OEE from OPC –UA.

Sl. No	Database Column	Parameter Name	Data Type	OPC UA - Node Id Parameter Tracking
1	currentTime	Server Timestamp	Float	NS0|Numeric|2258
2	opMode	Operation Mode	String	NS2|String|/Bag/State/opMode
3	cycleStart	Cycle Start	Float	NS2|String|/Plc/Q113.4
4	partCount	Part Count	String	NS2|String|/Channel/State/actParts
5	partState	Part State	String	NS2|String|/Channel/Parameter/R

Additionally, the inclusion of user variables demonstrates flexibility for custom configurations tailored to specific manufacturing requirements. Overall, this comprehensive tracking of parameters shown in **Figure. 5** which helps enables real-time monitoring of machine operations, facilitating enhanced productivity, efficiency, and quality in manufacturing processes with its resource utilization.

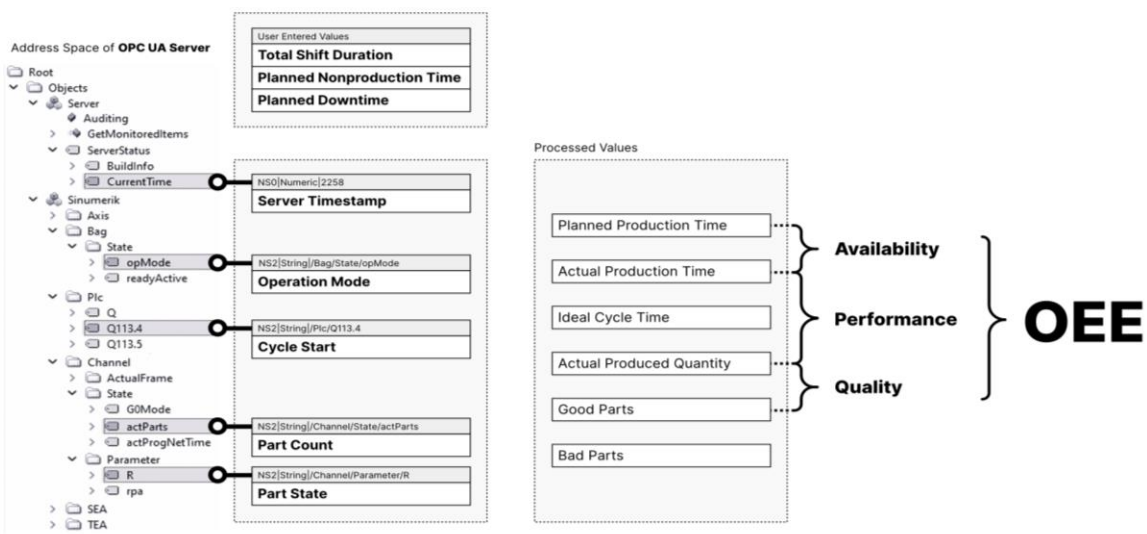

Figure 5: Internal flow of OEE Data from shop floor/MES to OEE Analytics

Overall Equipment Effectiveness (OEE) and its associated losses are computed based on a combination of user inputs and the parameters derived from functional parameters obtained from the computed structure. Machine-to-Machine (M2M) communication via OPC UA parameters from machines and operator-defined R parameters are also utilized. The experimentations were carried out considering the production companies, they would need to compute the OEE and OEE losses for the individual machines as well as to whole factory where OPC UA enabled machines are available. The work carried out at Smart Manufacturing Cell (SMC) of CMTI can be applied in mass production companies, batch production companies, limited production OEM's. Keeping in mind the module has been experimented to work in all the manufacturing scenario's, the experimentations and trails have been done at SMC cell. The smart manufacturing cell (SMC) of CMTI consists of Legacy machines and latest CNC machines. The machines are OPC UA enabled and these machines have been configured for data collection and OEE computations as indicated in **Figure.1** and **Figure.2.** Initially to validate the calculations of OEE and OEE losses, VMC machine available at Smart Manufacturing Cell has been used for the experimental try-outs. All the production events occur during the machining process like shift-wise timings, shift breaks, setting up the components, cycle times, job change overs, slow cycles, manual quality checking through operator entry has been experimented with VMC machine. Thereafter, the VMC machine was made to run in production mode while all the necessary data such as machine status, idling, cycle times & job changeovers were simultaneously measured and recorded. Figure 6 shows the parameters inputs used for computing OEE and OEE losses.

OEE and OEE losses are calculated based on

i. User Inputs/MES/Schedulers/Planners
ii. OPC UA Parameters from Machine and R parameter from Operator
iii. Calculations based on OPC Machine parameters

i. **User Inputs/MES/Schedulers/Planners:** This information should be provided by the user industry either through manually or through some connectivity
   - ✓ Scheduled Time/Available Time/Planned Production Time
   - ✓ Planned Down Time/Maintenance Activity
   - ✓ Planned running time per unit/Theoretical cycle time per unit
   - ✓ Shift Change/Other errors from user

ii. **OPC UA Parameters from Machine and R parameter from Operator**
   - ✓ Machine parameters through OPC
   - ✓ R Variables- User defined Parameters (R Parameters i/p by operator) through OPC UA for
     - Setup time
     - Bad part rejections
     - Minor stops

iii. **Calculations to be made for**
   - ✓ Cycle time of rejected parts using bad part rejections
   - ✓ Unplanned breakdown to is the sum of
     - Breakdown using cycle time information
     - Machine alarm information
   - ✓ Slow cycles

Figure 6: Parameter Inputs used for computing OEE and OEE losses

All the OEE & OEE losses calculations have been computed manually for our reference purpose. As the module has been developed to run in auto-mode, the software ser-vices for OEE & OEE losses have been computed. The software computations have been adjusted by doing the experiments in multiple iterations and continued till the software calculations are matching with the manual computations. The software validations of computing OEE & OEE losses are done for a week in VMC machine by carefully monitoring the machine performance along with other inputs indicated in **Figure 6**. Once the solution is validated, the AMS-VMC OEE and OEE losses software has been deployed in cloud for remote monitoring. The same approach has been carried out for Mazak H-400 machining center and Mono-200 turning machine. The OEE and OEE losses shopfloor level performance has been deployed in cloud for the remote monitoring. With this approach and validation done for the OPC UA enabled machines, the key performance indicators like OEE and OEE losses of the factory can be implemented in any manufacturing industries. The 'R' variable (User Variable) available in Siemen's controller 828D, 840 Dsl, 840D has been used as a part quality variable to communicate remotely by the machine operator to the OPC UA client. The operator enters the part quality as "accept" or "reject" using one of the R variables in the part program shown in **Figure 7** as in Human Machine Interface (HMI) of the controller.

N1 R [145] =1; Part accepts, its default state

N1 R [145] =0; Part reject, the operator enters whenever the previous machined part is rejected. Based on the operator input, the quality performance is computed by considering the part count register and counting the number of times the operator has indicated ‘reject’ in the production shift.

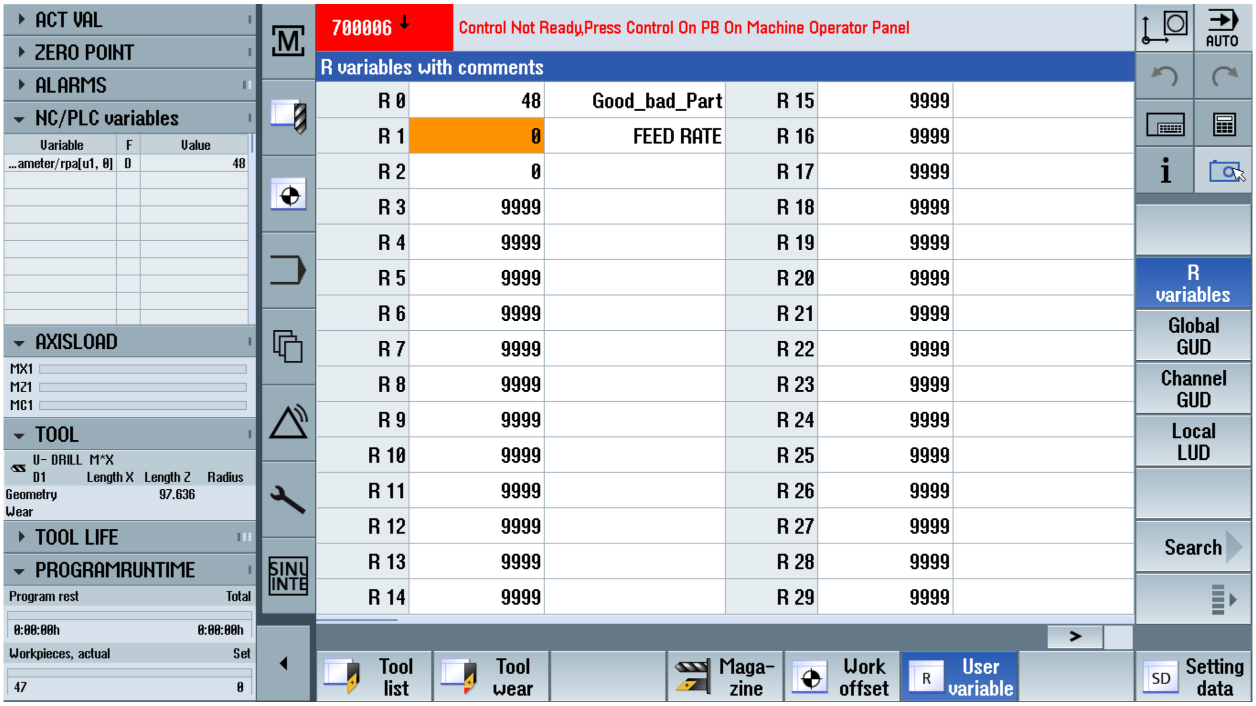

Figure 7: Configuration of R-variable for quality by manual user input by the operator.

Results and Discussion

To validate the Overall Equipment Efficiency (OEE) and OEE losses module, experiments were conducted using CNC machines at the Smart Manufacturing Cell of the Central Manufacturing Technology Institute (CMTI), including Vertical Machining Centers (VMC), Turning Machines, and Machining Centers. Initially, the module was tested with one CNC machine and then extended to other ma-chines in the factory. Data from machine parameters such as operating mode, program status, and machine status were used.

i. **Operating Mode (opMode):** The CNC machine's manner of operation is described by three modes: 0 = jog, 1 = manual data input (MDI), and 2 = auto (MEM mode). MEM mode indicates part productivity, while MDI and jog modes are regarded as non-productive time, resulting in production loss.
ii. **Program Status:** The state of the program loaded into memory. For example, a value of 3 might denote that the program is started, and a value of 1 might mean the program is completed.
iii. **Machine Status:** The current state of the machine, such as PRODUCTION, IDLE, or OFF. If no data is received, the machine is "OFF." The cost implementation table is outlined in **Table. 2** the financial aspects associated with deploying the complete solution for enhancing manufacturing efficiency through OPC UA-enabled OEE modules.

Table 2: Cost Implementation Table of the complete solution.

Cost Component	**Description**	**Amount ($)**
Equipment	Purchase of machinery, tools, etc.	NA
Software	Licensing fees, development costs, etc.	SAAS Module (40 Dollars/Machine)
Installation	Cost of installing equipment/software	Remote Installation.
Maintenance	Ongoing maintenance and support costs	10$/Annum
Other Expenses	Any other relevant expenses	NA
Total Cost	Sum of all expenses	50Dollars/Machine
Financial Metric	**Description**	**Amount ($)**
Total Benefits	Estimated financial benefits over a certain period (Year)	400$
Total Costs	Total cost of implementation	50$
Net Profit	Total benefits minus total costs	350$
ROI (%)	(Net Profit / Total Costs) x 100	700%

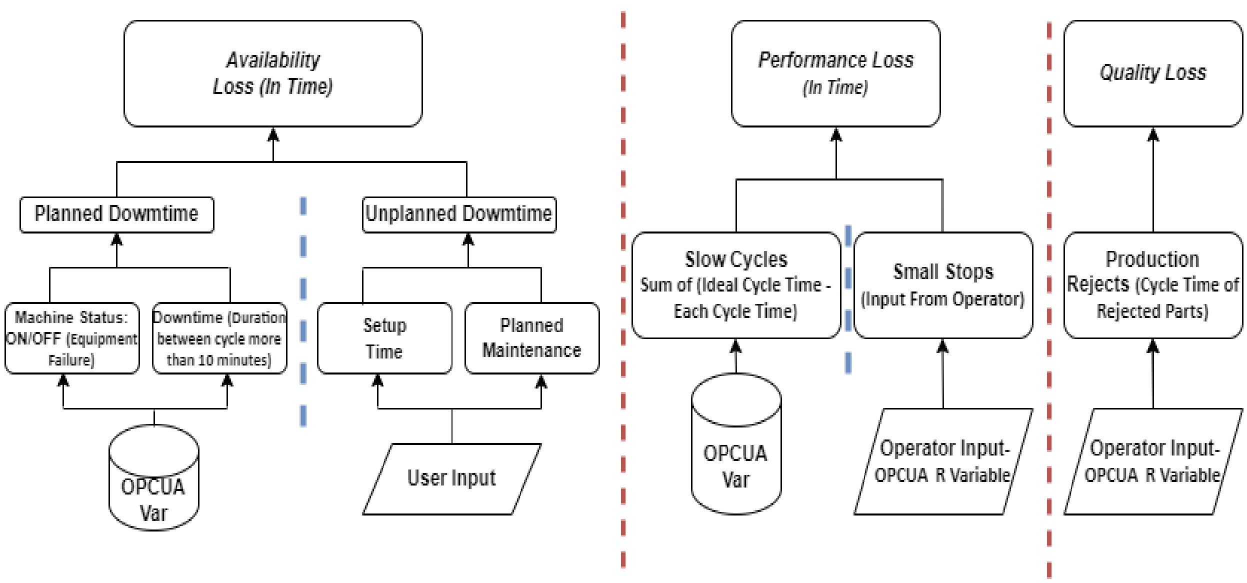

Figure 8: Parameter losses considered for Availability, Performance and Quality.

An overview of how various losses are measured and categorized in a manufacturing process, with a focus on Availability Loss, Performance Loss, and Quality Loss is covered in **Figure. 8**. Availability Loss is divided into Planned Downtime, which includes machine statuses like ON/OFF during equipment failures, captured through OPC UA variables, and Unplanned Downtime, such as setup time and planned maintenance, typically recorded via user input.

In **Figure. 9** the OEE (Overall Equipment Efficiency) monitoring system dashboard is shown. The **Figure. 10** presents a workshop-wide dashboard that consolidates key metrics like OEE, Availability, Performance, and Quality for multiple machines, providing a high-level overview of the production efficiency. Individual machines, such as Mazak H-400 and AMS-VMC, have their

OEE scores displayed, along with a summary of parts produced, highlighting both successful outputs and defects.

Figure 9: Production Analytics with its OEE & Workshop Efficiency for selected Date and Time.

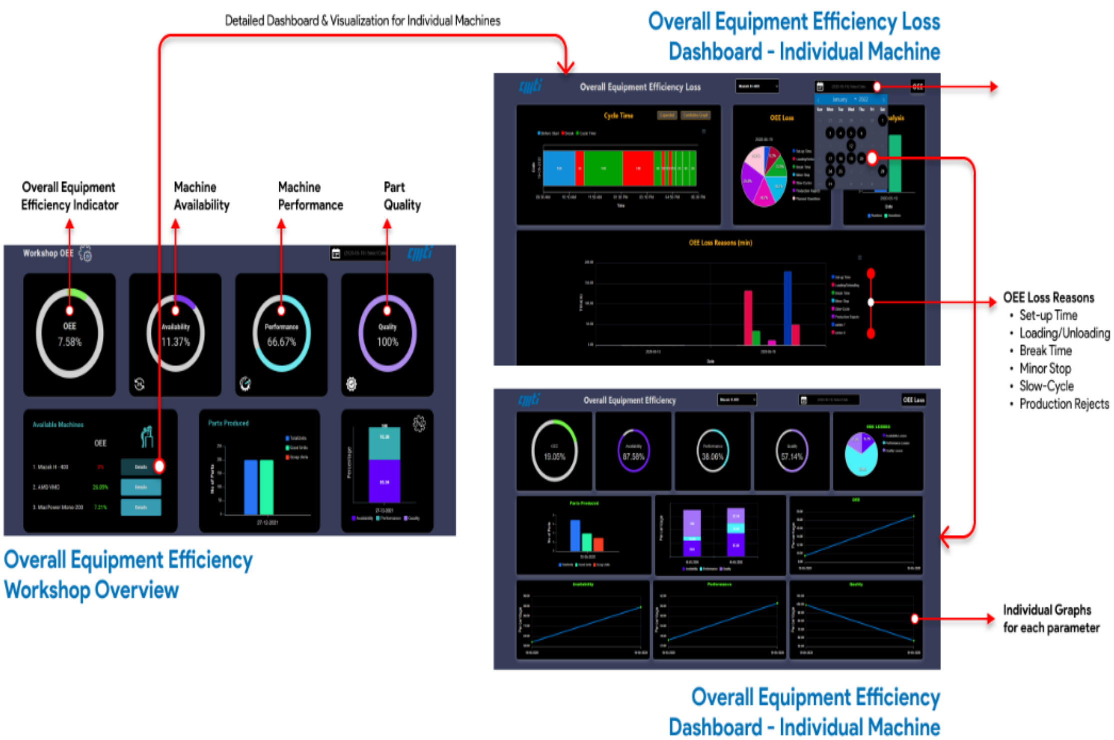

Figure 10: Overall Equipment Efficiency Dashboard Graphs & Analytics for Each Machines

The solution has been hosted both locally and, in the cloud, as shown in the **Figure. 11**. The solution has been hosted both locally and, in the cloud, utilizing web link www.cmti-india.com, which is accessible on the Internet to visualize and study the functionalities of each module.

Figure 11: OEE dashboards developed for Mobile and desktop application

The shift hours computations at the shopfloor are structured as presented in **Table. 3** and OEE parameter calculation and formulations are done with respect to the combination of user defined parameters and machine derived parameters. The ROI is then calculated as 60 to 70 days depends on the number of machines available in the factory.

Table 3: OEE metrics calculation table for Shopfloor with three machines.

	Parameter	**Machine 1**	**Machine 2**	**Machine 3**
USER	*Total Shift Duration*	480	480	480
	Planned Nonproduction Time	40	40	40
	Planned Downtime	80	60	80
	Planned Production Time	440	420	440
	Actual Production Time	320	360	300
OPC UA	*Machine IDLE Time*	140	124	172
	Machine PRODUCTION Time	320	336	288
	Ideal Cycle Time	16	16	16
	Ideal Production Quantity	20	22	18
	Actual Produced Quantity	18	20	17
	Good Parts	17	20	15
	Bad Parts	1	0	2
	Availability, A	72.73	77.27	68.18
	Performance, P	90	94.12	90.67
	Quality, Q	94.44	100	88.24
	Overall Equipment Efficiency, OEE	**61.82**	**72.73**	**54.55**
	Availability Loss	27.27	22.73	31.82
	Performance Loss	10	5.88	9.33
	Quality Loss	5.56	0	11.76
	OEE Loss	**38.18**	**27.27**	**45.45**
Shopfloor	**Shopfloor Availability**	**72.65%**		
	Shopfloor Performance	**85.4%**		
	Shopfloor Quality	**94.13%**		
	Shopfloor OEE	**58.4%**		

	Shopfloor Availability Loss	**27.35%**
	Shopfloor Performance Loss	**14.6%**
	Shopfloor Quality Loss	**5.87%**
	Shopfloor OEE Loss	**41.6%**

Conclusions

To show the benefit of adopting the digital transformation and its value to the Indian industries considering interoperability through M2M communication like OPC UA and its data for the computation of KPI's like OEE and OEE losses. The developed solution has been implemented, and the use of OPC UA has been demonstrated to gather data from CNC machines. The flow charts and the computations for calculating OEE and OEE losses were thoroughly examined. A discussion has been held on calculations based on OPC machine parameters in order to automatically compute OEE & OEE losses in real-time for User Inputs/MES/Schedulers/Planners, OPC UA Parameters from CNC Machine, and R parameter from Operator. The value of OPC UA data and its application use cases, this interactive software has been designed and implemented on-premises and in the cloud utilizing cmti-iiot.online web link, which is accessible on the Internet to visualize and study the functionalities of each module. The solution has been tested and demonstrated at Smart Manufacturing Cell at CMTI. The cost of implementing the proposed system is few thousands Indian Rupees (Few 10's of dollars) per machine, while the estimated total benefits over a certain period of one year would be at-least six times of the investment by monitoring the OEE and its losses through corrective measures.

List of Abbreviations

OEE - Overall Equipment Effectiveness
KPI - Key Performance Indicators
M2M - Machine-to-Machine
OEM - Original Equipment Manufacturers
MES - Manufacturing Execution System
VMC - Vertical Milling Centre
OPCUA - Open Platform Communication and Unified Architecture

Declarations

- **Availability of Data and Material:** The data and materials utilized in this study are available upon reasonable request. The data related to machine operational parameters, OEE calculations, and the OPC UA configurations, as well as any developed software tools or models, can be provided for research and academic purposes. Researchers interested in accessing these resources should contact the corresponding author.
- **Competing Interests:** The authors declare that they have no competing interests related to this study. There are no financial or personal conflicts of interest that could influence the research results or interpretations.

- **Funding:** This research was not supported by any funding body and had no role of external support in the design of the study, data collection, analysis, or interpretation of results.

Authors' Contributions

- T Narendra Reddy: Conceptualization, methodology, data curation, writing—original draft, and project administration.
- Nitesh K: Analysis, and writing—review and editing and Methodological guidance and manuscript review.
- Nachappa P P: OPC UA configuration, Analytics development, and validation of calculations.
- Prakash Vinod: Writing—review and editing, and validation.
- Dr. M A. Herbert: Supervision and project management.
- Dr. Shrikantha S. Rao: Methodological guidance and manuscript review.

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Declaration of interests

☒The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: